Signs and transitions:
Do they differ phonetically and does it matter?

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Abstract

The point of departure of this paper is the cluster of three pre-theoretical presuppositions (P) governing modern research into sign languages: (1) that a stream of signing consists of signs (S) and transitions (T), (2) that only Ss are linguistically relevant units, and (3) that there is a qualitative (e.g. phonetic) difference between Ss and Ts. Of these, the paper focuses on the relatively untested P3, which is used to back up P1 and P2, and investigates the velocity and acceleration properties of Ss and Ts on the basis of continuous motion capture data from Finnish Sign Language. The main finding of the study is that the speed of Ss is slower (and varies less) than that of Ts, but that Ss still involve more accelerating (and varying) motion. The purely linguistic interpretation of the results is that the slower speed of Ss enables the addressee to perceive more accurately the fine S-internal linguistic details, manifested by high acceleration. The more theoretical conclusion is that the results support all three Ps, but that only P3 is supported directly. As previous key research findings concerning Ts partly contradict P1 and P2, further research into Ts is called for.

**Keywords:** sign, transition, phonetics, motion capture, velocity, acceleration, Finnish Sign Language
1. Introduction

Modern research into sign languages supports three pre-theoretical presuppositions (P). The first (P1) holds that a stream of signing consists of signs and transitions. This presupposition has its roots in the same ideology that considers spoken language words to be surrounded by transitional gaps (for a specific discussion, see Wilbur 1990), and its effect can be seen perhaps most clearly in the methodology that has been used to handle signed video material collected for research purposes. In this process, the first step has always been to somehow segment the sign stream into signs and transitions in such a way that signs become marked explicitly (e.g. with glosses, or with annotation cells) and transitions implicitly as periods that are not signs (cf. the gaps between glosses and annotation cells). Some methodological frameworks, such as the transcription system originally devised by Liddell and Johnson (1989) and further developed by Johnson and Liddell (2011ab), have also focused on the explicit marking of transitions. In their system, the need to record transitions in sign language (as opposed to spoken language) has been emphasized on the grounds that the continuous visibility of articulators in sign language makes transitions appear more prominent in signing than in speech.

The second presupposition (P2) is linked directly to the first one. According to P2, signs are the primary focus of linguistic investigation whereas transitions are redundant periods of activity that are outside the realm of linguistic analysis. This presupposition can be traced back at least to Stokoe’s (1960) first linguistic analysis of American Sign Language, in which signs were defined as word-like combinations of meaning and form. Since then, the presupposition has been discussed and
established explicitly within the context of phonology – see for example Perlmutter (1990), van der Hulst (1993), and Brentari (1998) who specifically exclude transitions from their phonological discussion – but it holds equally well in other subdomains of sign language research too. An illustration of this is the newly emerging research area that aims to develop automatic sign recognition technology (see e.g. Duarte and Gibet 2010ab; Piater et al. 2010): the main aim of this work is to create a computer tool that will not only identify signs from a video but will also specifically disregard transitions. In the end, the influence of the presupposition can also be seen in the tradition of labeling sign languages as sign languages and not, for example, as transition languages.

P1 and P2 are backed up by the third more implicit presupposition (P3). This holds that sign and transition sequences are qualitatively different from each other. Both psychological and concrete arguments have been put forward to support the presupposition. From the psychological perspective, the most common claim has been that only the production of signs is intentional activity, transitions being unintentional and involuntary (see e.g. Perlmutter 1990; Wilbur 1990; van der Hulst 1993; Brentari 1998; Blondel and Miller 2001; Johnson and Liddell 2011b). More concretely, transitions have been claimed to be shorter in duration and to involve less muscular tension than signs and to be typically unable to carry beats as part of the rhythm (Wilbur 1990, 46). It has moreover been argued that for example handshape changes during transitions are discontinuous, whereas changes during signs are smooth and uninterrupted (e.g. Brentari 1998). However, some counterevidence to this last claim has also been put forward (Johnson and Liddell 2011b).
Recently, a set of phonetic differences between signs and transitions have been presented by Jantunen, Koskela, Laaksonen and Rainò (2010). On the basis of a pilot-stage computer-vision analysis of the motion characteristics of three different articulators (both hands, and head) on a video, Jantunen et al. suggest, first, that signs in general exhibit more variation than transitions in the amount of horizontal and vertical motion. Second, they suggest that transitions contain more moving interest points on the body than do signs. Finally, they propose that the combined speed of the three articulators is slower during signs than during transitions. Overall, the findings of the study by Jantunen et al. suggest that the production of signs is a more controlled activity than the production of transitions, the latter thus being more holistic and uncontrolled units. This seems to agree with other claims concerning the differences between signs and transitions, including, for example, the claim from the psychological perspective that only the production of signs involves intention.

It is reasonable to propose that physical – phonetic – evidence supporting P3 is important for the justification of both P1 and P2, although the validity of P1 and P2 cannot be considered necessarily dependent on the validity of P3. Unfortunately, however, the phonetic research carried out thus far has only scratched the surface of this issue, and making valid arguments on these grounds may be unwise. This line of thinking is further encouraged by a deeper look into the data and methodology of previous studies. For example, the research underlying the claim that the production of transitions involves less muscular activity has not been experimentally documented in any report (as far as the author of this paper is aware) and the findings presented, for example by Jantunen et al. (2010), are based only on a very small set of data and on the use of pilot-stage computer-vision technology. Consequently, it is suggested
that more phonetic research into the physical characteristics of signs and transitions is needed in order to further justify the tradition; not only to consider signs and transitions to be qualitatively different (P3), but also to divide the sign stream into signs and transitions (P1) and to focus on signs as primary units of linguistic investigation (P2).

This paper sets out to investigate the physical characteristics of signs and transitions. In particular, the paper examines whether sign and transition sequences identified from a stream of continuous signing are different in their velocity and acceleration properties (specifically: the magnitudes of their velocity and acceleration vectors) when the point of reference is the most salient part of the signer’s dominant hand, the index finger tip (e.g. Ojala et al. 2009; Ojala and Saakoski 2009; Ojala 2010). Velocity – defined generally as the rate and direction of change in position of an object – and acceleration – the rate of change of velocity over time – are the two first time-derivatives that can be calculated for any (moving) point in a three-dimensional space. As such, they represent the most basic physical features that can be investigated in a language that is built upon the principle of moving the hands and arms in space and they therefore provide a natural starting point to approach the theoretical assumptions presented and discussed above.

Methodologically, the paper treats both signs and transitions primarily as normative class notions. The author is well aware that this approach is likely to mask some sign-type or context-specific variation, such as the possibility that the velocity and acceleration properties of some type of signs, perhaps in some contexts, are similar to those of transitions, or vice versa. However, this choice of approach is deliberate and
motivated first and foremost by the nature of the P1, P2, and P3 that are the focus of this paper. On another level the choice is also motivated by the author’s involvement in work investigating methods by which signs could be automatically distinguished from transitions and could be identified from a video containing continuous signing (Jantunen et al. 2010; Karppa et al. 2010). This work will not be discussed further in this paper but it is expected – because such technology relies heavily on information about the motion characteristics of normative signs and transitions – that the results of the present investigation will provide additional background information for the technological work.

The study data were collected from motion capture technology and comprise approximately 52 seconds of continuous monologue type signing of Finnish Sign Language. Motion capture data are considered today to be the most accurate type of data available for phonetic sign language research and are expected to provide a reliable basis both for the making of claims regarding the differences between signs and transitions and for theoretical conclusions resulting from them. The downside of motion capture data is that collection requires laboratory settings and therefore never yields the most natural type of data. However, because the data from the present study constitute continuous signing (and not, for example, signs or phrases produced in isolation), they tend to the more natural end of the general motion capture data continuum.

The text is structured as follows. The next section first discusses the current conception of the sign and the transition from a definitional perspective and then reviews, briefly, some key findings of the marginal research into transitions. The
following section presents the data, method, and results of the present study, and the section after that discusses the implications of the results. The final section concludes the paper.

2. Defining signs and transitions

2.1 The sign

The sign is arguably the most central notion and unit in research into sign languages (see especially P2). This being the case, it is somewhat surprising that direct and explicit attempts to define it have been scarce (in the name of fairness, this is the case with most basic concepts in linguistics). Two examples of the rare attempts made to capture the overall essence of the sign are Sandler (1999) and Zeshan (2002). Sandler discusses the sign from the perspective of phonology. She argues that a prototypical phonological sign is a monosyllable that includes only one set of selected fingers, is produced at one major place of articulation, and, if two-handed, is restricted in the way the hands interact with each other (see Battison’s 1978 symmetry and dominance conditions summarized below). Zeshan, on the other hand, approaches the sign from the classical perspectives of semantics, morphology, and syntax. She argues that the key properties of the grammatical sign are its conventionalized meaning and its ability to occur independently. These properties are the same that define also the grammatical word (e.g. Bloomfield 1933) but Zeshan claims that the sign and the word are, strictly speaking, not one hundred percent analogous. According to her, the two differ, for example, in the degree of internal cohesion (signs allow more internal modification, words are internally more stable units) and in the nature of the possible
morphological processes (signs include more simultaneous morphology, words include sequential morphology).

The definitions given by Sandler (1999) and Zeshan (2002) for the phonological and grammatical sign, respectively, approach the sign from the perspective of an abstract language system. More concrete phonetic characterizations of the sign have typically been made from the viewpoint of describing the articulators that participate in the production of signs (see e.g. the different sign language dictionaries). Standard articulatory characterizations of a sign generally begin by stating first that a sign is produced manually, that is, with the hand(s). Secondly, these characterizations typically state that the sign may be either one- or two-handed, and that the hand(s) may either contact or not contact some other part(s) of the body. Finally, it is typically concluded that, in the case of two-handed signs (Battison 1978; cf. above), the hands may move independently with a symmetrical or alternating motion, or be ordered in such a way that the dominant hand acts upon the stationary non-dominant hand. In the latter case, the handshapes of the two hands may be identical or different; if different, the handshape of the non-dominant hand belongs to a subset of handshapes possible for the dominant hand.

Most characterizations of the sign, including the linguistic and phonetic ones presented above, have emphasized the nonlinear – or atemporal – nature of the sign. Direct attempts to define or even discuss the sign from a temporal perspective have been relatively marginal despite the fact that signs (like words) are inherently also linear units, that is, units produced over a period of time. However, linguistically the sign has been approached as an inherently temporal notion at least in the fields of
segmental and prosodic phonology. Following the work of Liddell (1984), those interested in segmental phonology have defined the sign as a sequence of dynamic and static segments (e.g. movements and holds). Prototypically, such a segmental sign has been argued to contain at least one dynamic segment during which the hand produces a path movement (e.g. Liddell and Johnson 1989; Sandler 1989; Perlmutter 1992). The practitioners of prosodic phonology, on the other hand, have typically defined the sign with the help of the notion of syllable. Prototypically, a sign defined this way is claimed to consist of at least one syllable that, in turn, is understood generally as one dynamic phonological movement unit; if such a unit is not part of the underlying representation of the sign, the grammar is said to add a short, straight epenthetic path movement to the surface realization of the sign (e.g. Perlmutter 1992; Sandler 1993; Brentari 1998; Jantunen and Takkinen 2010).

Phonetically, the nature of the linear sign has been discussed both within the field of sign language corpus work (e.g. Crasborn and Zwitserlood 2008; Johnston 2009; Mesch 2010) and in the context of the sequential sign notation system recently published by Johnson and Liddell (2011ab). In the field of corpus linguistics, the sign has been defined as a semantically coherent sequence of sign stream during which the hand(s) move from the initial location of the sign to the final location of the sign. It has been argued that the most important practical features marking the beginnings and ends of signs in this approach are the visible changes in the direction of the movement of the hand(s). A similar view of the sign is argued for also by Johnson and Liddell. In their system, the beginnings and ends of linear signs are defined as postural gestures that are describable with a finite set of phonetic features. In practice, these correspond to positions of the articulator(s), marked by a change in the direction of the movement
when none of the structural features (handshape, place of articulation, orientation and nonmanual features) of the sign changes (Johnson and Liddell 2011b, 412). These moments may or may not have a phonetically significant duration, and they are always surrounded by trans-forming gestures during which the articulator(s) move to a different position. Trans-forming gestures may be sign-internal or transitional and, in this system, they are further classified into sub-classes according to the type and nature of the movement of the articulator (e.g. the main division between ballistic and antagonist movements, based on muscular activity).

Naturally, the level of abstraction and the conventions from which the sign is approached in each of the above mentioned fields and models varies. Nevertheless, it is still reasonable to conclude that they all see the prototypical linear sign as a relatively similar type of unit that includes a (sequence of) phonologically specifiable movement(s) of the hand(s) from point $a$ to point $b$, both marked by a change in the direction of the movement. This is the general view on the linear sign that is followed in the present paper. For the concrete identification of signs from a sign stream, a method based on the practical definition that has emerged from the field of sign language corpus work will be used.

### 2.2 Transitions

In contrast to the notion of sign, the notion of transition has provoked little definitional discussion. To put it briefly, the term is accepted to mean two things. First, it can refer to the movements of the hands that occur between signs and transfer the hand(s) from the end location of one sign to the start location of the next sign
(Blondel and Miller 2001, 41-43). Second, it can refer to the movements that occur in between sign-internal syllables (ibid.). Of these two uses, the first one is clearly more widespread and typical, and it is also the definition of transition that will be used in this paper. Sign-internal transitions are not explicitly discussed due to the theory-dependent status of the signed syllable (e.g. Perlmutter 1990), referred to in the definition of sign-internal transitions.

As mentioned in the Introduction, transitions have not been the primary target of linguistic investigation (mainly because of the assumption that they are not linguistic; see P2). However, there are a few research domains in which issues relating to transitions have been touched upon. These are the domains of sign phonetics, sign recognition, and sign language poetry. Because this marginal research into transitions indicates interesting phenomena modern sign language research should address more explicitly, and because they as such provide extra grounding for the interest of the present paper to investigate transitions, the (what are believed to be) key findings of this research are outlined here for each of the three research domains.

A key finding in the first domain is that the most salient moments in signing can be associated not only with signs, but also with transitions. The phenomenon has been addressed, for example, by Wilcox (1992), who in his phonetic study on American Sign Language fingerspelling claimed that in fingerspelling transitions are more salient than the actual target handshapes. This particular finding must perhaps be interpreted within the more general framework of motion perception, in which moments of motion (cf. transitions) overall enhance perception more than moments of stasis (cf. handshapes) (e.g. Bruce and Green 1990; Wolfe et al. 2008). However, the
finding suggests that transitions may function as perceptual cues that indicate to the addressee the immediate forthcoming linguistic units. If this is the case, the finding partly contradicts the mainstream approach in which the function of transitions is seen simply as being an involuntary and redundant effect of the hand moving from the end of one meaningful unit to the beginning of another meaningful unit.

A key finding concerning the second research domain, sign recognition, is that the lexical recognition point of signs is located within the transition (e.g. Grosjean 1981; Clark and Grosjean 1982; Emmorey and Corina 1990; Arendsen et al. 2007; ten Holt et al. 2009). For example, in their recent study on the distribution of information in a signal over time, ten Holt, van Doorn, de Ridder, Reinders and Hendriks (2009) found that meaning is conveyed to a fairly considerable extent by sections of the signal identifiable as the transitional beginnings and ends of signs. Similar results have been reported also in more traditional sign recognition studies since Grosjean (1981): the studies have shown that the recognition of a sign takes place during the transitional sequence of the hand; that is, before the actual production of the sign. The finding has been explained in terms of continuously visible articulators, which provide the addressee with redundant coarticulatory information and thus allow the addressee to guess the meaning of the forthcoming linguistic unit in advance of its actual production (e.g. ten Holt et al. 2009). However, from a more critical perspective the finding can be interpreted as meaning that the linguistic meaning also attaches to transitions. This in turn raises the question of whether transitions – or at least parts of them – should in fact be considered parts of signs.
A key finding in the final research domain of transitions – sign language poetry (e.g. Blondel and Miller 2001; Sutton-Spence and Kaneko 2007) – is that transitions, like signs, are often modifiable. For example, Blondel and Miller (2001) have shown how a sign language poet may stretch the duration of transitions as if transitions were proper signs or, alternatively, stress the transition in a way similar to actual signs. The importance of this finding is that it seems to contradict rather directly the current view on transitions as not involving intention, as with some previous claims concerning, for example, the non-ability of transitions to bear linguistic stress. Obviously, a direct need for further research into transitions also within this domain is indicated.

3. The study

3.1 Data and method

The data for the present study come from Finnish Sign Language and comprise approximately 52 seconds of continuous monologue describing a winter-time cycling incident near the University of Jyväskylä, Finland. The main character of the story is a signer who is a native deaf user of Flemish Sign Language, but who has subsequently moved to Finland and has come to master Finnish Sign Language as well. That the signer is fully competent and fluent in Finnish Sign Language is evidenced, for example, by the fact that the signer teaches Finnish Sign Language at the University of Jyväskylä. Although the story as such is a monologue, it was told to another native Finnish Sign Language signer sitting opposite to the narrator.
The data were recorded in the Motion Capture Laboratory of the Department of Music at the University of Jyväskylä in the fall of 2010. The recording was done using one digital video camera and eight infrared cameras, which were included in the motion tracking system of the laboratory. The video camera was a standard Panasonic (NV-GS400) digital video camera shooting at a speed of 25 fps. The camera was positioned to face directly the signer sitting in a chair; its distance from the signer was measured to be 3.2 meters.

The actual motion capturing was done with eight ProReflex MCU120 cameras, physically attached to the laboratory’s roof in a symmetrical arrangement. The cameras were controlled through the Qualisys Motion Tracking system and they shot with the speed of 120 Hz (120 fps). Each camera recorded data from 20 small ball-shaped markers attached to the signer’s body. The head included four markers at forehead level; each arm and hand included seven markers on the main joint positions (shoulder, elbow, ulnar and radial wrist joint, the most proximal joint of the index finger, tip of the index finger, and tip of the thumb); and the upper torso included two markers, one in the middle of the chest and one on the back. Although the total number of markers recorded was 20, only the data from the marker attached to the index fingertip of the dominant hand were used in the present study. The main reason for this was that, of the two manual articulators, the dominant hand is the more salient and governs the activity of the nondominant hand (Battison 1978; Jantunen 2010). Furthermore, it is primarily the index finger that is responsible for controlling the rhythm and speed in signing; this is argued to be the case with both one- and two-handed signs (Ojala 2010; Ojala et al. 2009; Ojala and Salakoski 2009).
The recorded data were first preprocessed in the Qualisys system by an experienced assistant who attached each marker a body part identity. After this, the data were transferred to MATLAB (Macintosh Intel version R2009b) software in which any gaps that had occurred during the recording were filled. Gap fills were done by using a specific algorithm included in the MoCap Toolbox (ver. 1.2.1), developed by the researchers in the Department of Music at the University of Jyväskylä for the purpose of kinematic analysis of motion capture data (Toiviainen and Burger 2010). The same toolbox was used also in the actual MATLAB processing of the data. This included, first, the calculation of the first two time derivatives – velocity and acceleration – for all the three dimensions (x, y, z) of the tracked index finger marker on the basis of its location data and, second, the calculation of the magnitudes (i.e. lengths, or Euclidean Norms) of velocity and acceleration vectors for the three-dimensional data. In practice, the calculation of vector magnitudes converted the three-dimensional data sets into one-dimensional sets that, in very general terms, can be said to indicate the amount of and changes in the velocity (i.e. speed) and acceleration of the marker. In the present study, signs and transitions were investigated on the basis of this magnitude data, alternatively called the Norm data.

Following these steps, all the numeric data were added to specific time codes and imported into ELAN (EUDICO Linguistic Annotator, see http://www.lat-mpi.eu/tools/elan/) annotation software as track data together with the video data. In ELAN, the numerical data and video were synchronized, after which all the signs included in the story were identified on the basis of video using the following phonetic sign identification criteria:
A sign begins in the video frame that immediately precedes the frame in which the dominant hand first shows movement away from the initial location of the sign; if the sign includes only a movement executed from the wrist or finger joints, the beginning of a sign corresponds to the frame that immediately precedes the frame in which the initial handshape or orientation of the dominant hand first starts to change. A sign ends at the frame immediately following the frame in which the global movement of the dominant hand has reached its end or in which the dominant hand still holds a posture or a hand configuration of the sign.

Using these preliminary video-based annotations as reference points, the beginning and end locations of signs were then determined anew by relying on the graphical information about the precise locations of the index finger marker, displayed in ELAN’s track panels. In practice, the beginnings and ends of signs were re-tuned on the basis of changes occurring in the direction of the movement of the dominant hand index finger, detectable through the highest and lowest peaks of location-time curves.

At this point, a mechanical step of identifying and annotating transitions between signs was also performed. This was done automatically with ELAN’s “Create Annotations from Gaps...” function. After this step, 117 signs and 118 transitions were identified from the data. However, the total number of transitions was subsequently decreased by two due to the removal of the lengthy beginning and end transitions of the story. Ultimately, the number of transitions total 116.

After the identification of signs and transitions, their average values of velocity and acceleration magnitudes were calculated with ELAN’s “Export Track Data...” function. The values were then exported as Tab-Delimited Text to a text file and imported into Microsoft Excel 2008 for Mac (version 12.2.0) in which the statistical
calculations, shown in the results section of this paper, were performed. The qualitative judgments in the study were made by visually observing the graphical plots displaying the velocity magnitude and acceleration magnitude of the tracked index finger marker. These plots were created in MATLAB on the basis of the Norm data.

One methodological remark needs to be made. This relates to the representation of the borders of signs and transitions in this study. These borders are now represented as being easily defined; one good reason for this is the fact that ELAN requires the determination of beginnings and ends of linguistic units accurate to one thousandth of a second. However, in reality phonetic borders are never clear-cut due to continuous coarticulation – in fact, it has been demonstrated that the border between a sign and a transition can even spread over several frames (Jantunen 2010; Johnson and Liddell 2011b). Consequently, despite the practical requirements imposed by the present method, all sign-transition borders in the study must be interpreted as fuzzy.

3.2 Results

The descriptive research question of the present study is: Do sign and transition sequences differ in terms of their velocity and acceleration magnitude? In the study, the question was approached both quantitatively and qualitatively on the basis of continuous motion capture data from Finnish Sign Language. All data were tracked from the marker attached to the tip of the dominant hand index finger. The results of the study are presented in the following sections.
3.2.1 Quantitative results

The data included 117 signs and 116 transitions (excluding the longer beginning and end transitions of the continuous story). The average duration of signs, calculated separately on the basis of the ELAN time codes of the present data, was 221.8 ms (SD=163.5). The average duration of transitions was 150.6 ms (SD=101.0). This indicates that in the present data, signs were roughly a third longer in duration than transitions. However, as indicated by standard deviations, the durations of both signs and transitions varied considerably. In general, the duration of signs exhibited more variation than that of transitions.

The descriptive statistics concerning the magnitude of the velocity vector – or speed – of signs and transitions, based on averages calculated in ELAN, are shown in Table 1. The box plot chart in Figure 1 represents the main findings graphically.

TABLE 1.

FIGURE 1.

The results show that, in the data, the speed of signs was slower than the speed of transitions (by average and median). Student’s t-Test (two-tailed, two-sample, unequal variance) indicated that this difference was statistically significant (Sig.=0.024). Moreover, the results indicated that, in the data, the speed of transitions varied more than that of signs (by SD, variance, and range).
The descriptive statistics concerning the magnitude of the acceleration vector – or the amount of acceleration – of signs and transitions, based on averages calculated in ELAN, are shown in Table 2. The box plot chart in Figure 2 represents the findings graphically.

{TABLE 2.}

{FIGURE 2.}

The results show that, in the data, the amount of acceleration during signs was higher than the amount of acceleration during transitions (by average and median). This difference was found to be statistically very significant (Sig.=0.0011; two-tailed, two-sample, unequal variance Student’s t-Test). Moreover, the results indicated that, in the data, the amount of acceleration of transitions varied less than that of signs (by SD, variance, and range).

3.2.2 Qualitative findings

The data were investigated qualitatively by observing the shape of the plotted velocity and acceleration magnitude curves during signs and transitions. In general, as evidenced by Figures 3 and 4, which represent the velocity and acceleration magnitude plots for the first nine signs of the data, the shape of both curves varied considerably during both signs and transitions. An obvious cause for the variation was that the tip of the dominant hand index finger is the most active part of the hand and,
consequently, it was in constant, rapid, global and local motion for the duration of the signing.

{FIGURE 3.}

{FIGURE 4.}

Despite the fact that movement of the index finger tip was seemingly erratic, some overall observations regarding the motion characteristics of signs and transitions can nevertheless be made from the plots. First, a type of asymmetry between signs and transitions was detected from sequences that contained only signs in which the handshape remained flat and open during the whole production of the sign. An example of such a sequence is the combination of repetitive signs FALL-DOWN-HEAVILY and PILE-UP-ON-THE-GROUND, displayed as the last two signs in Figures 3 and 4. Within these type of signs, each sequential movement contained typically a speed profile of a relatively balanced parabola and an acceleration curve including two peaks, one of which was typically associated with the speeding up phase of the movement (i.e. was a literal acceleration peak occurring in the left half of the velocity magnitude parabola) and the other of which associated with the subsequent slowing down part (i.e. was a deceleration peak occurring in the right half of the velocity magnitude parabola). However, during transitions between such signs, the speed profile always included a bump of some sort (in the case of the two examples in Figure 3, two distinct velocity peaks even resulted) and acceleration values were always significantly lower with no major peaks of acceleration associating with any point of the velocity magnitude curve (minor peaks were often
documented, as in the case of the example in Figure 3). The phenomenon is here interpreted to be caused by a lapse in muscular tension during transitions. The analysis is supported by the relatively low amount of acceleration during these transitions, which, in turn, suggests – by Newton’s physics – that the production of transitions in these cases involves a relatively low amount of (muscular) force.

Yet another type of asymmetry between signs and transitions was found: the bulks of very high and steep acceleration peaks within a very short period of time were in general sign-internal. Two examples of such bulks are contained in signs ME and WINTER, represented as the first and the fifth sign respectively in Figure 4 (and 3). In both cases the index finger moved independently within the sign during its more global movement. For example, in the case of the indexical first person pointing sign ME, the dominant hand started its movement from the rest position on the signer’s lap and continued its global movement upwards all the way to the sign REMEMBER. The sign ME that occurred halfway to this movement was produced only by rapidly flexing the index finger from its base joint towards the chest and slightly supinating and pronating the wrist. These condensed bulks of high peaks of acceleration are interpreted as a typical feature only of signs that include local motion from finger joints. This analysis is supported by the fact that such bulks were not present in signs in which the handshape remained flat and open throughout their production.

A clear difference in the behavior of signs and transitions in terms of their velocity and acceleration characteristics was found by observing the four total instances of two very iconic and descriptive signs, LOOK-AT-AS-SHE-WALKS-BY (n=1) and UPRIGHT-PERSON-WALKS-BY (n=3). The velocity magnitude curve for the first
sign is given below in Figure 5 and the acceleration magnitude curve for the same sign in Figure 6. The sign itself is represented with a series of actual frames captured from the video in Figure 7.

{FIGURE 5.}

{FIGURE 6.}

{FIGURE 7.}

The velocity and acceleration magnitude curves of all the instances of both signs were near zero flat lines, similar instances of which were not found from any of the investigated transitions. In other words, apart from the immediate beginning and end of these signs, their speed was almost zero and constant for their duration, and there was almost no acceleration involved in their production. That transitions did not contain such specific velocity and acceleration magnitude profiles suggests that the type of motion, indicating high (muscular) control of the movement, is typical only of signs.

Both of the signs investigated (with all their instances) correspond to verb-like signs, which Liddell (2003) treats as including analogical, gesture-like information (cf. indicating verbs and depicting verbs). This further supports the idea that having a constant near zero velocity and acceleration magnitude curve is a property specifically linked to these particular types of signs (see also Johnson and Liddell 2011b). This
interpretation is supported by the fact that similar movement profiles were not identified in any other signs in the data.

The velocity and acceleration magnitude profiles of these signs are explained as a result of iconic coding of the specific temporal nature of the event the signs represent in their movement. Of the two signs, the first (Figure 7) depicts iconically, through partial blending (Liddell 2003), the main character’s head and eyes slowly turning and following a woman passing the cycling incident scene in the story. The second sign is a similar iconic sign that represents the woman walking by the incident scene slowly. In both signs, the movement of the dominant hand is steady and prolonged, representing the motion in the actual event in a temporally one-to-one-manner.

4. Summary and discussion

The present study investigated the velocity and acceleration magnitudes of sign and transition sequences by asking if there was a physical (phonetic) difference between the two. Sign and transition sequences were defined in accordance with the current conception of these units, they were treated as normative class-notions and they were identified from the data comprising approximately 52 seconds of continuous motion captured Finnish Sign Language signing. Although very short in duration and featuring signing from only one signer, the data are considered to be, nevertheless, relatively representative within the context of other motion capture studies (e.g. Wilbur 1990; Wilcox 1992; Ojala 2010), which so far have concentrated mainly on the investigation of rather isolated signs and phrases.
The results of the present study indicate strongly that signs and transitions are different in terms of their velocity and acceleration characteristics. Quantitative results showed that the speed of signs was significantly slower than the speed of transitions, and that the speed of transitions varied more than that of signs. On the other hand, the amount of acceleration was significantly higher during signs than during transitions, and the amount of acceleration varied less during transitions than during signs. It was also established – in a general accordance with the claim made, for example, by Wilbur (1990) regarding American Sign Language – that signs were roughly a third longer in duration than transitions, and that the duration of signs exhibited slightly more variation than the duration of transitions.

Qualitative investigation indicated a similar difference between signs and transitions. Visual observation of velocity and acceleration magnitude plots revealed two asymmetries and one clear difference between the two. The first asymmetry concerned the interplay between the speed and the amount of acceleration in transitions occurring in between signs containing an open flat handshape: in these transitions, although their production involved speeding up and slowing down, their production was still relatively forceless. The second asymmetry concerned the distribution of bulks of very high and steep acceleration peaks during a very short period of time: such bulks, which is it proposed are the result of rapid local movements of the index finger (to which the tracked marker was attached), were always sign-internal and did not occur in signs with an open flat handshape. The main qualitative difference that was observed between signs and transitions concerned the production of two highly iconic signs. These signs were produced in the data at a slow and constant speed that involved no acceleration. The resulting constant flat and
(near) zero velocity and acceleration magnitude curves were not identified in transitions, which suggests that transitions cannot be controlled in the way that signs can. The fact that these signs are also representatives of signs containing a gestural component (Liddell 2003) further suggests that the specific motion characteristic is a specific property of signs belonging to this class (see also Johnson and Liddell 2011b). However, this should be tested with wider data.

The main physical difference between signs and transitions revealed both by the quantitative and qualitative investigation – i.e. that the speed of signs is slower (but varies less) than that of transitions, but that signs still involve more accelerating (and varying) motion – can be interpreted linguistically in terms of the classical principles of ease of perception and articulation (e.g. Zipf 1949). On the one hand, the slow and relatively non-varying speed of signs indicates that the signer maximizes the recipient’s possibility of perceiving the fine linguistic distinctions within signs, manifested, among other things, by the existence of rapidly accelerating sign-internal movements that in general give signs the relatively high yet varying acceleration value. On the other hand, the relatively fast speed of transitions and their low acceleration value (and, therefore, also force) suggest that the signer does not put much effort into their production. However, we should not depend too much on this interpretation: it is based on the methodological decision to treat signs and transitions as normative class-notions and is likely to overlook the fact that the motion characteristics of some signs in some contexts may actually resemble those of transitions, and vice versa. That this is indeed the case is strongly suggested by the variation in velocity and acceleration exhibited both by signs and transitions.
Nevertheless, the results agree with and provide experimental grounding for the previous claims typically presented to back up the pre-theoretical assumption that there is a qualitative difference between signs and transitions (i.e. P3). Two of the most concrete of these claims, directly supported by our present findings, were that the production of transitions involves less muscular activity than the production of signs (e.g. Wilbur 1990) and that the speed of the articulator(s) during signs is slower than their speed during transitions (Jantunen et al. 2010). Consequently, the main psychological claim that only the production of signs involves intention (cf. Perlmutter 1990; Wilbur 1990; van der Hulst 1993; Brentari 1998; Blondel and Miller 2001) can also be said to be supported: the conclusion we can reach from that, that signs are produced with a higher (muscular) force than transitions, indicates a more controlled and purposeful (intentional) production of signs.

By strengthening the conclusion that signs and transitions as classes are physically different units, the results of this study also directly support P3. Because P3, in turn, has been used to back up P1 and P2 – positing that there are signs and transitions, and that only signs are linguistically relevant units – the results provide support indirectly also for these pre-theoretical presuppositions. However, as was noted previously in the Introduction, the validity of P1 and P2 does not depend entirely on the validity of P3. In fact, and interestingly, despite the suggested validity of P3, the other findings from the field of marginal research into transitions seem, at least partially, to work against P1 and P2.

Let us consider briefly the case of P2, which claims that only signs are linguistically relevant units. First, although taken as one of the guiding principles in modern sign
language research, P2 is contradicted directly by the fact that transitions in poetry are modifiable both durationally and for the purpose of expressing emphatic stress (Blondel and Miller 2001). This, in turn, implies that at least in the poetic register transitions are not always nonlinguistic and, minimally, that P2 does not hold across all domains of language use. Second, the fact that signs are typically recognized on the basis of their initial and also final transitions (ten Holt et al. 2009) may also be taken to contradict the nonlinguistic analysis of transitions. It may be that this phenomenon simply results from the continuous visibility of the articulators in sign language, which allows the intended message to be guessed in advance (as has been suggested, by e.g. ten Holt et al. 2009), but it may also be that at least some parts of the transitions should in fact be considered parts of signs. This interpretation is suggested at least by research into the recognition of spoken language words. According to Grosjean (1981) and Clark and Grosjean (1982), for example, the recognition of spoken words always requires that at least part – around 30 to 80 percent, depending on the context – of their physical-acoustic form is produced and heard. However, should this analysis be correct for signs, it would actually indicate not the linguistic role of transitions as such, but rather a more fundamental and ontological need to perhaps re-think the notion of sign to cover also parts of (the current) transitions. Further research into the matter is obviously needed.

Blondel and Miller’s (2001) study on sign language poetry holds an important consequence also for the seemingly unchallenged assumption P1. If transitions can be modified in duration, they can, logically, also be reduced to non-existence. This is in fact suggested by Blondel and Miller in their proposal of the existence of a context-
dependent continuum in the phonological interpretation of transitional movements (Blondel and Miller 2001, 42-43):

When the transition is stressed or otherwise exaggerated [...] we are faced with the fact that we are dealing with an exceptional variety of phonological structure where transitional movements are treated in a manner similar to lexical movements in core phonology. This exceptional phonology might be seen as occupying one end of a continuum, the other end of which is occupied by conversational signing.

In short, if transitions are treated as phonological, which contradicts P2, they are no longer transitions but (parts of) signs, which contradicts P1, which claims that a stream of signing consists of signs and transitions. Again, further in-depth research into the matter is needed.

5. Conclusion

This paper has discussed signs and transitions. The investigation of velocity and acceleration magnitudes of signs and transitions on the basis of motion capture data from Finnish Sign Language indicated that there is a physical difference between the two, and that this matters because it provides direct support for the pre-theoretical tradition of considering signs and transitions to be qualitatively different types of units. Indirectly, the finding may also be taken to support the pre-theoretical assumptions that divide signing into signs and transitions and treat only the first as linguistically significant moments. However, other findings from the field of otherwise marginal research into transitions suggest that the tradition of disregarding
transitions is not always a valid approach. As a result, in future work the consequences of these findings must be further investigated.

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References

Arendsen, J., A. van Doorn, and H. de Ridder. 2007. When and how well do people see the onset of gestures? Gesture 7:305-342.


### TABLE 1. Descriptive statistics of velocity magnitude (speed) averages of signs and transitions. Velocity magnitude is measured in meters per second.

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Signs (n=117)</th>
<th>Transitions (n=116)</th>
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</thead>
<tbody>
<tr>
<td>Average</td>
<td>1046.37</td>
<td>1173.89</td>
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<tr>
<td>Median</td>
<td>1053.03</td>
<td>1147.90</td>
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<tr>
<td>SD</td>
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<td>Variance</td>
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<tr>
<td>Min</td>
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<tr>
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<tr>
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<td>2694.70</td>
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<tr>
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<td>776.17</td>
<td>834.73</td>
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<tr>
<td>Quartile 3</td>
<td>1260.47</td>
<td>1458.23</td>
</tr>
<tr>
<td></td>
<td>Signs (n=117)</td>
<td>Transitions (n=116)</td>
</tr>
<tr>
<td>----------------------</td>
<td>--------------</td>
<td>---------------------</td>
</tr>
<tr>
<td><strong>Average</strong></td>
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<td><strong>Quartile3</strong></td>
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<td>24465.25</td>
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TABLE 2. Descriptive statistics of acceleration magnitude averages of signs and transitions. Acceleration magnitude is measured in meters per second per second.
FIGURE 1. Box plot chart of velocity magnitude (speed) averages of signs and transitions. Velocity magnitude is measured in meters per second.
FIGURE 2. Box plot chart of acceleration magnitude averages of signs and transitions. Acceleration magnitude is measured in meters per second per second.
FIGURE 3. Velocity magnitude (speed) plot for the first nine signs of the data. Velocity magnitude is measured in meters per second (y-axis). X-axis represents time in frames.
FIGURE 4. Acceleration magnitude plot for the first nine signs of the data. Acceleration magnitude is measured in meters per second per second (y-axis). X-axis represents time in frames.
FIGURE 5. Velocity magnitude (speed) plot for the depicting sign LOOK-AT-AS-SHE-WALKS-BY and for the transitions preceding and following it. Velocity magnitude is measured in meters per second (y-axis). X-axis represents time in frames.
FIGURE 6. Acceleration magnitude plot for the depicting sign LOOK-AT-AS-SHE-WALKS-BY and for the transitions preceding and following it. Acceleration magnitude is measured in meters per second per second (y-axis). X-axis represents time in frames.
FIGURE 7. The sign LOOK-AT-AS-SHE-WALKS-BY represented with frames captured from the video.